MAP 73

MAJOR LEVELS OF GREAT SALT LAKE AND LAKE BONNEVILLE

May 1984

by

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Scale 1:750,000
1 inch equals approximately 12 miles
Contour interval 500 feet

Base map courtesy of U.S. Geological Survey

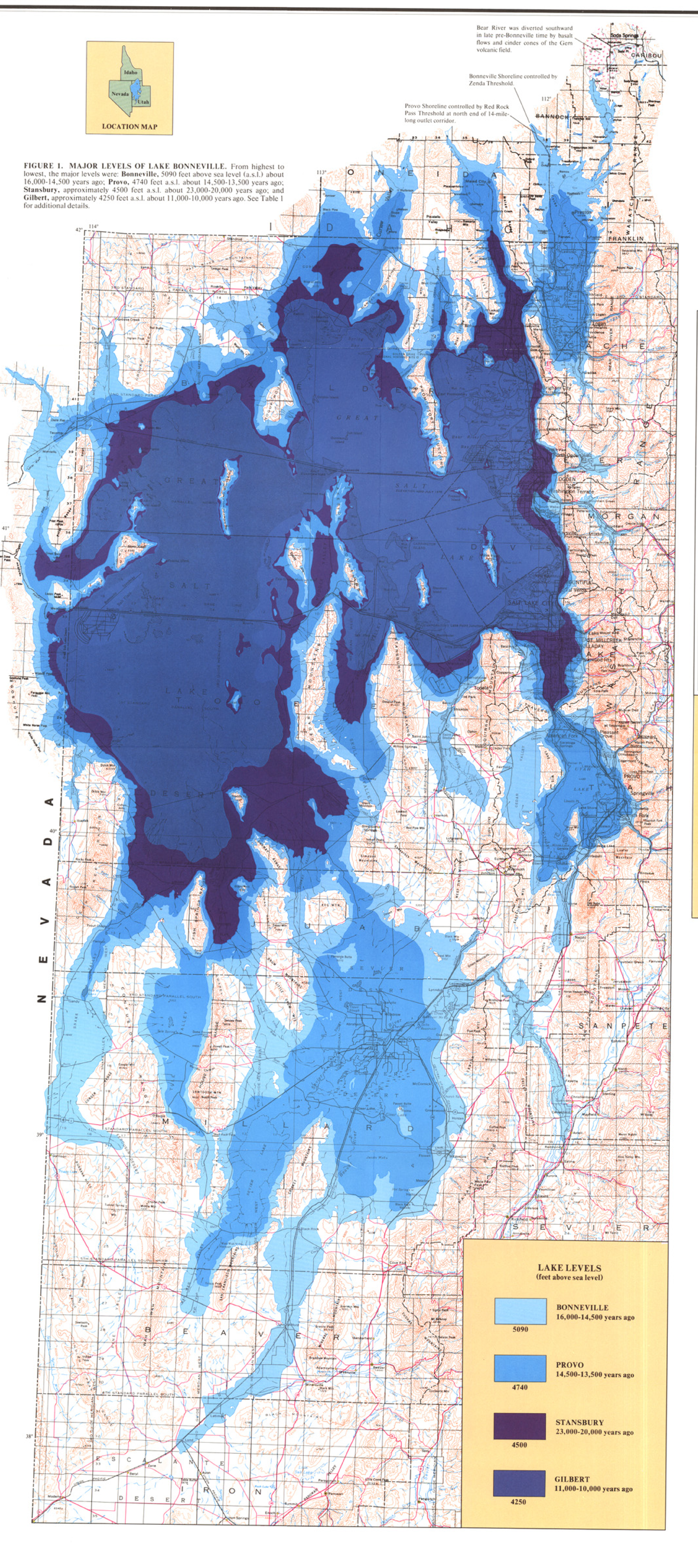

FIGURE 1. MAJOR LEVELS OF LAKE BONNEVILLE. From highest to lowest, the major levels were: **Bonneville,** 5090 feet above sea level (a.s.l.) about 16,000-14,500 years ago; **Provo,** 4740 feet a.s.l. about 14,500-13,500 years ago; **Stansbury,** approximately 4500 feet a.s.l. about 23,000-20,000 years ago; and **Gilbert,** approximately 4250 feet a.s.l. about 11,000-10,000 years ago. See Table 1 for additional details.

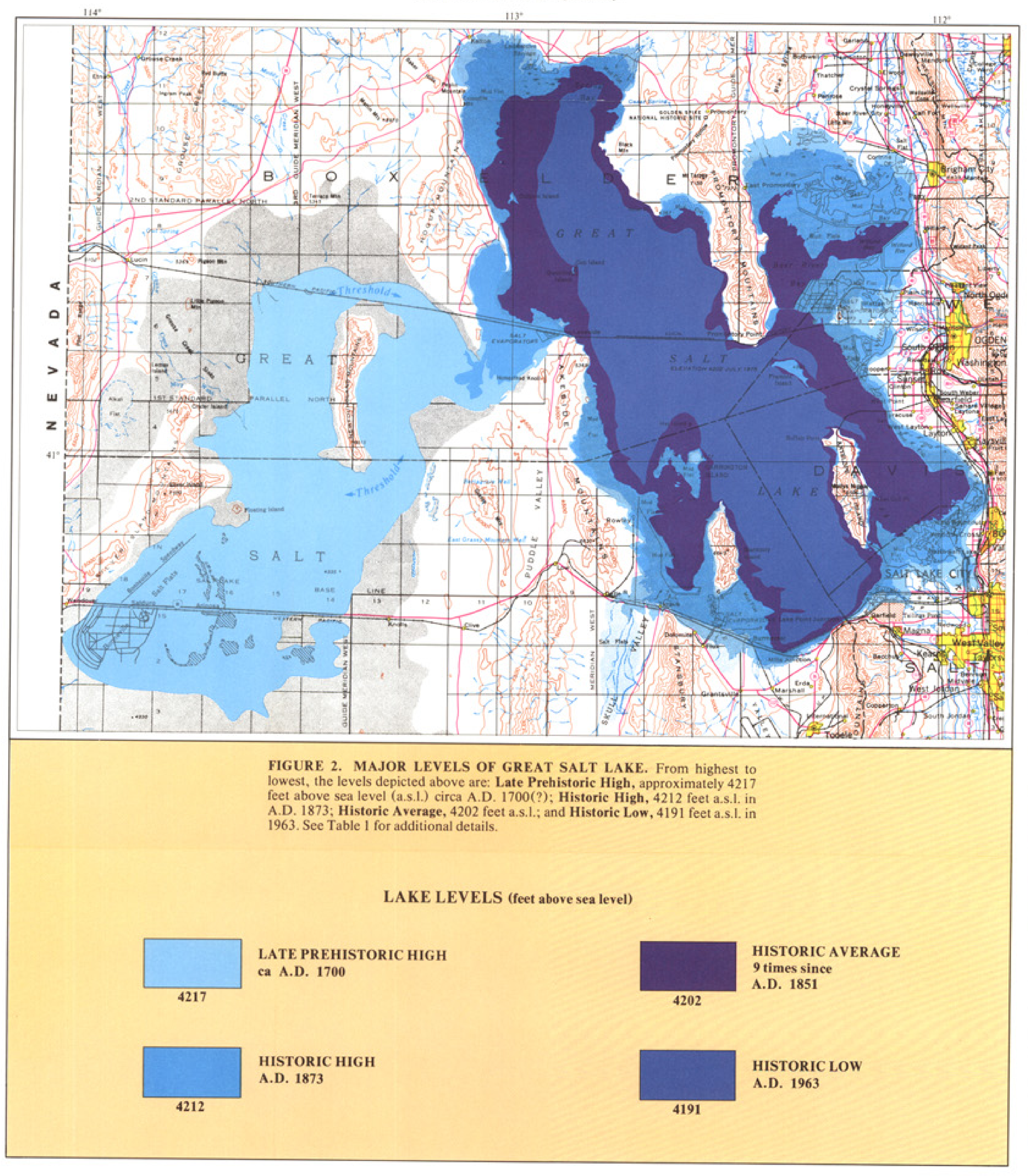

FIGURE 2. MAJOR LEVELS OF GREAT SALT LAKE. From highest to lowest, the levels depicted above are: **Late Prehistoric High,** approximately 4217 feet above sea level (a.s.l.) circa A.D. 1700(?); **Historic High,** 4212 feet a.s.l. in A.D. 1873; **Historic Average,** 4202 feet a.s.l.; and **Historic Low,** 4191 feet a.s.l. in 1963. See Table 1 for additional details.

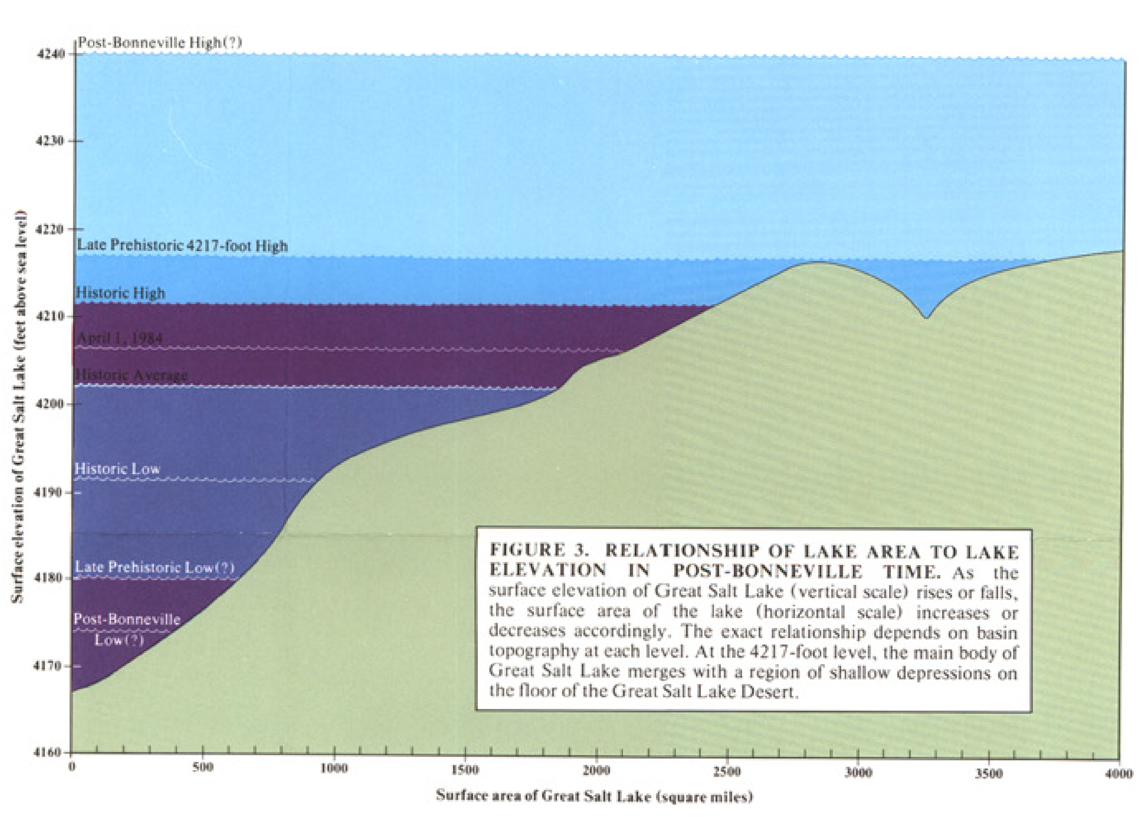

FIGURE 3. RELATIONSHIP OF LAKE AREA TO LAKE ELEVATION IN POST-BONNEVILLE TIME. As the surface elevation of Great Salt Lake (vertical scale) rises or falls, the surface area of the lake (horizontal scale) increases or decreases accordingly. The exact relationship depends on basin topography at each level. At the 4217-foot level, the main body of Great Salt Lake merges with a region of shallow depressions on the floor of the Great Salt Lake Desert.

TABLE 1. Significant shorelines and lake levels of Great Salt Lake and Lake Bonneville.

Shoreline/ Level	Approximate age (years before present)	Elevation (feet above sea level)	Approximate surface area (square miles)	Salinity	Level controlled by	Distinguishing characteristics
Stansbury	23,000-20,000	4500	9,300	Moderately saline	Climate	Tufa deposits, variable expression, often not distinctive; conspicuous above oil refineries and near Kennecott smelter.
Bonneville	16,000-14,500	5090 [1]	19,800	Relatively fresh; hard water	Threshold at Zenda near Red Rock Pass, Idaho; spilled to Snake River.	Highest shoreline traceable for over 2000 miles around basin.
Provo	14,500-13,500	4740 [1]	14,400	Relatively fresh; hard water	Threshold at Red Rock Pass, Idaho; spilled to Snake River.	Tufa deposits, very distinctive, large deltas entering lake, e.g., at Logan, Brigham City, Ogden, Sandy, and Orem-Provo.
Gilbert	11,000-10,000	4250 [1]	6,600	Saline	Climate	Not conspicuous, but recognizable near Syracuse, Magna, Mills Junction, and northwest of Great Salt Lake.
4217	At least twice in last 3000 yrs; most recently possibly circa A.D. 1700.	4217	3,700 [2]	Saline	Climate and Great Salt Lake Desert expansion of surface area and evaporation.	Small beach berms and deltas.
4212	A.D. 1873	4212	2,400	Saline	Climate	Wave-washed beach level.
4202	Nine times since A.D. 1851.	4202	1,800	Saline	Climate	Little geomorphic evidence.
4191	A.D. 1963	4191	900	Saline, saturated	Climate	Little geomorphic evidence.
Very low	Most recently possibly circa A.D. 1200.	4180(?)	600(?)	Saline, saturated	Climate	Submerged giant desiccation polygons and buried salt layer.

[1] Because the weight of the deep lakes in the Lake Bonneville basin depressed the earth's crust as much as 240 feet, subsequent rebound has caused the elevations of certain shorelines to be substantially higher in the central part of the basin.
[2] This includes 2800 square miles of water surface in the main part of the Great Salt Lake basin and 900 square miles in the Great Salt Lake Desert, west of the 4217-foot threshold region.

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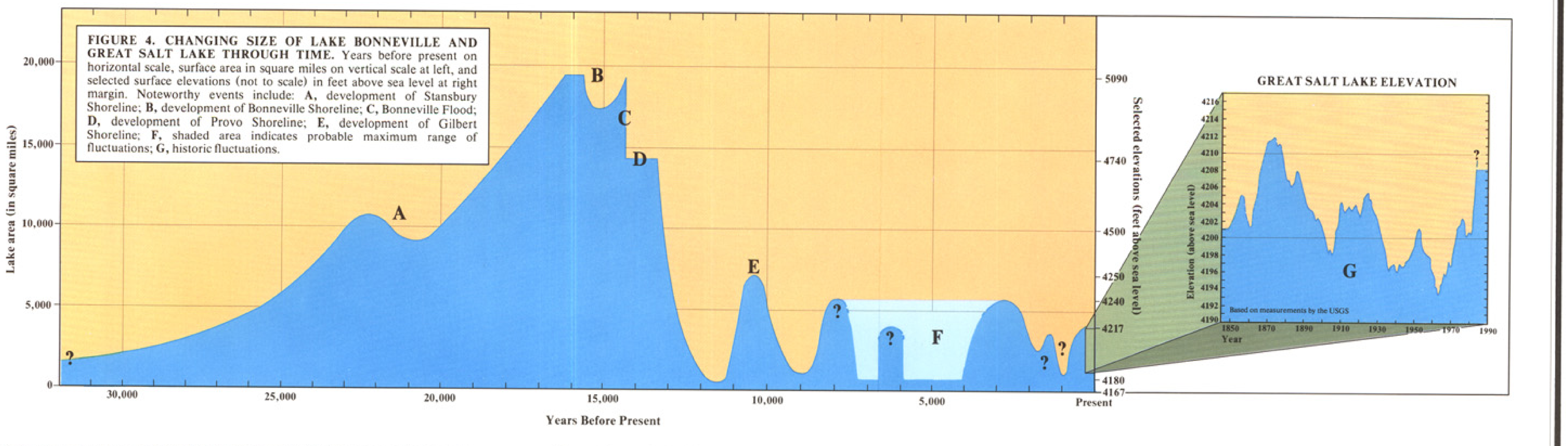

FIGURE 4. CHANGING SIZE OF LAKE BONNEVILLE AND GREAT SALT LAKE THROUGH TIME. Years before present on horizontal scale, surface area in square miles on vertical scale at left, and selected surface elevations (not to scale) in feet above sea level at right margin. Noteworthy events include: **A,** development of Stansbury Shoreline; **B,** development of Bonneville Shoreline; **C,** Bonneville Flood; **D,** development of Provo Shoreline; **E,** development of Gilbert Shoreline; **F,** shaded area indicates probable maximum range of fluctuations; **G,** historic fluctuations.

Introduction

GREAT SALT LAKE has intrigued and challenged the explorers, tourists, petroleum geologists, mineral extractors, brine-shrimp harvestors, transportation engineers, health professionals, wildlife biologists, meteorologists, climatologists, hydrologists, geologists, urban planners, and government officials who have tried to understand or control it. Management of the lake and prediction of lake levels are of particular concern since its sudden rise in 1983, which destroyed or damaged millions of dollars of property that year alone by flooding and also created severe high ground-water and drainage problems in the adjacent lowlands. Rising levels of Great Salt Lake must be understood as a geologic hazard if management of the lake is to be effective. Most attempts to predict future levels of the lake for management purposes have relied upon the 140-year historic record. This map summarizes geologic and historic evidence of the most significant lake levels and flood plains of the Great Salt Lake basin over the last 32,000 years.

Investigations of the rise and fall of Great Salt Lake and its predecessors

Investigations beginning with Captain Fremont in 1843 recognized evidence that a succession of deeper lakes had once occupied the basin of Great Salt Lake. The most obvious evidences of these older lakes are beaches, deltas, spits, and wave-cut cliffs which formed along the shorelines of the deeper lakes and which are now exposed at irregular intervals up to 1130 feet above the present lake.

G. K. Gilbert, first with the Wheeler Survey in the 1870s and later with the U.S. Geological Survey, completed a remarkable study of these prehistoric lake features. He established that, in the latter part of Pleistocene time, a lake with a maximum depth of at least 1000 feet covered an area of about 20,000 square miles in what is now northwestern Utah, northeastern Nevada, and southeastern Idaho (fig. 1). He named the lake Lake Bonneville after Captain Bonneville, an earlier explorer in the region. Gilbert determined that at its highest level, which he named the Bonneville Shoreline, Lake Bonneville overflowed the rim of the Great Basin near Red Rock Pass in southeastern Idaho. At the lowest point on the rim, about 5090 feet above sea level, Lake Bonneville spilled into a tributary of the Snake River. He concluded that these waters suddenly breached the relatively unconsolidated sediments forming the rim, quickly scoured to bedrock, and released a catastrophic flood down the Snake River. This event, now known as the Bonneville Flood, reduced the surface elevation of Lake Bonneville in a short time [probably in less than a year] to a more stable level at about 4740 feet above sea level. Gilbert named this post-flood level the Provo Shoreline. He noted that the shorelines which formed when the lake was at the Bonneville and Provo levels are now at considerably higher elevations in the central part of the lake basin than around its edges. He correctly concluded that the weight of the water in the deep lake had depressed the earth's surface when the shorelines were formed. When the water was removed, crustal rebound elevated the shorelines in the central part of the basin. Gilbert noted that an excess of evaporation over inflow must have drawn the lake down from the Provo Shoreline. Gilbert's final report on Lake Bonneville was published in 1890 as U.S. Geological Survey Monograph 1. For the next half century, very little was added to the understanding of the lake developed by Gilbert.

Since the 1940s, numerous studies using new topographic maps, aerial photographs, new techniques for soil and lake-bed studies, and new techniques for dating sediments and archaeological materials have contributed to a rapidly growing body of information on Great Salt Lake and Lake Bonneville. These studies have confirmed much of Gilbert's general history of Lake Bonneville. They have also refined the chronology of major deep-lake events and are leading to a better understanding of many of the lower lake stages that postdate Lake Bonneville (fig. 2 and 3).

Geography of the basin

The Great Salt Lake basin and the larger Lake Bonneville basin of which it is a part are in the Basin and Range physiographic province, which is characterized by generally north-trending ranges and basins. This distinctive topography has developed over the last 20 million years, as the region has extended in a generally east-west direction. Extension has thinned the brittle upper crust, which has broken in north-trending blocks that have either rotated or differentially subsided to produce the basins and ranges. As the crust thinned, regional subsidence has occurred with the greatest subsidence along the major eastern and western margins of the physiographic province. It is this regional subsidence near the eastern margin of the Basin and Range province that produced the Lake Bonneville basin.

Predecessors of Great Salt Lake

Pre-Bonneville levels—The general region of the Lake Bonneville basin has been an area of internal drainage for much of the last 15 million years, and lakes of varying sizes likely existed in the area during all or most of that time. Changes in local and regional drainage patterns and climate over this period are recorded in the late Cenozoic sediments that underlie the basin floor to depths of up to 10,000 feet or more. The last major change in the configuration of the Great Salt Lake drainage basin occurred between 130,000 and 30,000 years ago when a series of volcanic eruptions in the Soda Springs area of southeastern Idaho permanently diverted the Bear River away from its previous course to the Snake River and redirected it southward into what is now Utah. During the last major ice age prior to that diversion, perhaps from about 150,000 to 130,000 years ago, a lake only a couple hundred feet less deep than Lake Bonneville existed in the Lake Bonneville basin and then receded. Lake levels appear to have been relatively low during times of interglacial climate that predominated from about 130,000 until shortly after 30,000 years ago.

Stansbury level—In response to the climate of the most recent major ice age, Lake Bonneville's birth and development apparently was underway by 25,000 years ago, but its rise was stalled about 23,000 years ago when the lake's elevation was about 4500 feet above sea level (fig. 4). For reasons that appear related to climate rather than topography, the lake level did not rise appreciably above this elevation for about three thousand years, thereby forming the locally prominent Stansbury Shoreline.

Bonneville level—The lake then resumed its general rise until it reached the 5090-foot level on the rim of the basin, and began overflowing at Zenda just north of Red Rock Pass, by about 16,000 years ago. For over a thousand years the lake fluctuated several times near this level and formed the highest or Bonneville Shoreline before catastrophic failure of unconsolidated material in the outlet channel released a deluge of floodwaters into the Snake River, probably between 15,000 and 14,000 years ago. The lake rapidly lowered about 350 feet. When the outlet channel was eroded to resistant rock, the lake level again stabilized and the Provo Shoreline, in many respects the most conspicuous of all, was formed.

Provo level—The lake remained at the 4740-foot level, with water flowing out through Red Rock Pass and on to the Pacific Ocean via the Snake and Columbia Rivers, until sometime between 14,000 and 13,000 years ago. With the termination of the last major ice age, the lake began a substantial decline in level and by 12,000 to 11,000 years ago had receded to at least as low as its historic levels.

Gilbert level—Between 11,000 and 10,000 years ago the lake rose to an elevation of about 4250 feet, forming the Gilbert Shoreline, and then again declined. This marked the end of Lake Bonneville, and the birth of its peripatetic successor, Great Salt Lake.

Prehistoric levels of Great Salt Lake

IN THE LAST 10,000 years Great Salt Lake has fluctuated between low levels, but never completely dry, and high levels in the range of 4217 to 4240 feet above sea level. In the cycles of alternating moist and dry climate that occurred during the last 10,000 years, low lake levels are indicated by shallow-water sediments in cores from the bed of the lake, and by polygonal networks of giant dessication cracks which cover extensive areas of the lake bottom that are now under as much as 20 feet or more of water. The 4217-foot level is controlled by a pair of low topographic divides that separate the Great Salt Lake Desert basin in the west from the main body of the Great Salt Lake basin. At the 4217-foot level the area of the lake increases abruptly from 2800 square miles to 3700 square miles. Geochemistry and stratigraphy of bottom sediments indicate that the lake has reached or exceeded this level at least twice in the last 3000 years. Archaeological evidence from sites on the Bear River and Weber River deltas suggests that one of these upward fluctuations took place in the last 400 years, when the Little Ice Age of the last five centuries is known to have similarly affected many other regions in the northern hemisphere; paleoclimatic modeling suggests that the lake may have been near this level about A.D. 1670-1700.

Historic levels of Great Salt Lake

HISTORIC data on the level of Great Salt Lake began with Fremont's observations in 1843. The first gage to measure the lake level was established in 1875 and for most of the time since then monthly or semimonthly measurements of the lake's surface elevation have been obtained. The lake level reached an historic high of about 4211.5 feet in 1873 and an historic low of 4191.35 feet in 1963. Over the historic period, the average elevation has been a little above 4200 feet. In September, 1982, the lake level was 4200 feet, the same as measured by Fremont in October, 1843.

Factors that influence the level of the lake

Great Salt Lake is the lowest water surface in a large drainage basin that includes much of northwestern Utah, and parts of northeastern Nevada, southeastern Idaho, and southwestern Wyoming. In addition to a large desert area west of the lake, which generally captures little precipitation, the basin includes areas of much higher precipitation in the Wasatch Range, western Uinta Mountains, and Wasatch Plateau. Because the basin is closed topographically and has no outlet, ultimately the only loss of water is through evaporation. In the shorter term, any precipitation that falls in this large drainage basin either returns to the atmosphere through evaporation, flows into Great Salt Lake, or recharges ground-water aquifers. The level of Great Salt Lake goes through an annual cycle in response to seasonal variations in evaporation, precipitation, and stream flow. During the winter and spring, evaporation is relatively slight and the lake rises. In late spring or early summer, the evaporation increases and exceeds inflow and the lake level begins a decline that continues until evaporation decreases in the fall. The seasonal rise and fall of the lake is normally less than 2 feet. The greatest rise was 5.2 feet recorded in 1982-83 and the least decline was 0.5 feet, also recorded in 1983.

Inflow—Great Salt Lake receives water from three sources: direct precipitation on the lake, streams discharging into the lake, and ground water discharging into the lake. Although the relative contributions from these sources vary widely from year to year, the historic average is estimated by the U.S. Geological Survey to be 66 percent from streams, 31 percent from direct precipitation, and 3 percent from ground water. Bear River contributes 59 percent of the streamflow, over half of which enters the river below Soda Springs. Approximately 95 percent of the stream discharge is into the water body south of the Southern Pacific Railroad causeway and east of Promontory Mountains.

Consumptive use of water in the drainage basin has an effect on the lake level. Modeling of the effect of consumption of water during the period of general lake-level decline before 1965 indicated that the lake level in 1965 was about 5 feet below what it would have been if no consumptive use had occurred. During wet cycles the consumptive use for irrigation decreases and the effect on the lake level may be less pronounced.

Importation of water from the Colorado River system adds to the inflow into the lake. Water imported into the Great Salt Lake basin to date has had little effect on lake level.

Evaporation—The only loss of water from the lake is by evaporation, which is controlled mostly by climate. Cool, cloudy summers greatly reduce evaporation from the lake.

Surface area also influences evaporation. When long-term variations in weather increase precipitation or decrease evaporation, the volume, surface area, and elevation increase. When the surface area increases, the evaporation from the lake increases, and when the evaporation equals inflow, the lake volume stabilizes. By expanding or contracting its surface area, the lake continuously moves toward equilibrium with the weather and climate of its basin.

At certain elevations, the lake expands over a topographic threshold and significantly increases its surface area with little additional rise in lake level. The lowest such threshold occurs at the 4174-foot level and has been submerged for several thousand years. Another exists at the 4217-foot level, where the lake expands westward into the Great Salt Lake Desert (West Desert) and abruptly increases its surface area by nearly one-third.

Another factor that influences evaporation is the salinity of the lake waters: the greater the salinity, the lower the evaporation rate. The salinity of portions of the lake has been considerably altered by dikes, causeways, and evaporation ponds. These structures have also altered natural patterns of surface area, elevation, and lake circulation.

Summary

GEOLOGICALLY speaking, Great Salt Lake is the latest in a long succession of older, often more extensive lakes that have expanded and contracted off and on for the past 15 million years. Lakes 800 feet or more deeper than the present lake have occupied the Lake Bonneville basin twice in the past 150,000 years, although for much of that time the lake has been as low as or lower than at present. In the last 3,000 years, the lake has reached the 4217-foot level or above at least twice, and has been lower than its present level several times. There is some evidence that during this time period the lake receded to near the 4180-foot level. There is substantial evidence to suggest that the lake in the last 400 years reached the 4217-foot level and may have persisted near that level for at least 30 years.

In historic time, the lake continues to fluctuate in response to changes in precipitation, inflow from streams, ground-water discharge into the lake, and to changes in evaporation from the lake. The historic low level of the lake was 4191.35 feet in 1963 and the historic high level of the lake was about 4211.5 feet in 1873.

The 4217-foot level of the lake is controlled by topography west of the lake, where the 50-foot-deep Great Salt Lake depression and the broad-but-shallow (7-foot-deep) Great Salt Lake Desert depression are joined at that elevation across two thresholds north and southeast of the Newfoundland Mountains. At 4217 feet the lake expands nearly one-third in area, thus increasing its evaporative surface. There is no such lake-stablilizing topography below 4217 feet except at about 4174 feet, where a now-submerged threshold a few feet high separates the lowest area on the floor of the lake, west of Promontory Point, from an area almost as low south of Promontory Point. The historic high of 4211.5 feet was not controlled by topography but responded entirely to climatic conditions. The historic flood plain of Great Salt Lake can be designated as 4212 feet. However, geologic evidence shows established risk to 4217 feet for planning purposes, or slightly higher if appropriate allowance is made for set-up of water levels by dynamic conditions such as storms and seiches; the potential for set-up under dynamic conditions varies locally.

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